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Dependence of microwave surface impedance on crystallographic orientation in $YBa_2Cu_3O_{7-x}$ thin films

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Abstract : We report the variation of microwave surface resistance (R_s) and residual penetration depth $\lambda(0)$ of YBCO thin films as a function of orientation of the films Three thin film samples A, B and C have been studied. As revealed through XRD patterns, film A is partially *c*-axis oriented, film B has better *c*-axis orientation while film C is fully *c*-axis oriented The modified end plate replacement technique operating at 10 GHz in TE_{011} mode and sapphire loaded dielectric resonator technique operating at 13 6 GHz in $TE_{01\delta}$ mode were used for the measurement of R_s and $\lambda(0)$. The value of R_s (13 6 GHz, 65 K) for samples A, B and C have been found to be 1.607, 1 356 and 1 037 mΩ respectively Lower values of R_s (65 K) = 930, 780 and 600 $\mu\Omega$ have been measured at 10 GHz for these films. The values of $\lambda(0)$ (13.6 GHz) have been found to be 1950, 1830 and 1650 Å for the films A, B and C respectively. As the degree of orientation of *c*-axis grains increases in thin films, the Josephson coupling gets stronger and the value of R_s and $\lambda(0)$ decreases.

Keywords : Microwave surface resistance, YBCO thin films, grain orientation

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1. Introduction

The crystallographic defects in metallic conductors have been a source of power loss from dc to electromagnetic wave frequencies and their control with the increase of purity from 99.5–99.9995% for hyperconductors accompanied by large increase in the resistivity ratio ρ (300 K)/ρ (20 K) from 50–6000 is reported in the literature. Low-T_c metallic superconductors with low values of R_s (10 GHz) ≈ 25 $\mu\Omega$ and $\lambda(0)$ ≈ 1400 Å at liquid helium temperature have however been in use in microwave superconducting electronics for quite some time. With the discovery of high-T_c cuprate superconductors, various studies have been conducted on YBCO ceramic material processed under different conditions and

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whereas in the sample B, the intensity of the 113, 116/123 and 213 peaks diminish and peaks corresponding to the 103/110 and (00n) planes only appear. The film C contains peaks corresponding to (00n) planes only. Film A is partially c-axis oriented, film B has better c-axis orientation while film C is fully c-axis oriented. Other characteristics of the samples are given in the Table 1. The variation of R_s of the samples with temperature at

Table 1. Characteristics of the samples

Samples	A	B	C
T_C (K)	87	88	90
ΔT_C (K)	1.7	1.5	1.4
R_s (10 GHz, 65 K) (μΩ)	930	780	600
R_s (13.6 GHz, 65 K) (mΩ)	1.607	1.356	1.037
$\lambda(0)$ (13.6 GHz) (Å)	1950	1830	1650

10 GHz is given in Figure 2 whereas the corresponding results at 13.6 GHz are shown in Figure 3. The rate of fall of the microwave surface resistance (dR_s/dT) just below T_C has

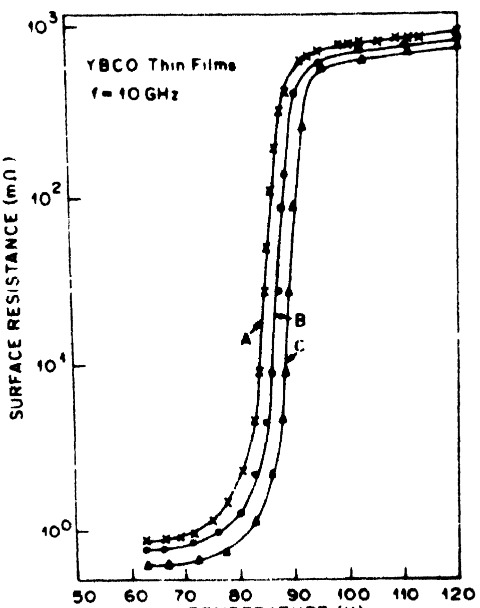

Figure 2. Variation of R_s (10 GHz) of the samples with temperature.

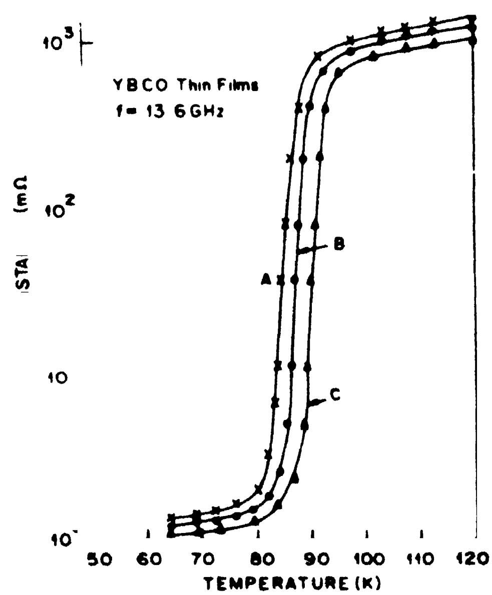

Figure 3. Variation of R_s (13.6 GHz) of the samples with temperature.

been found to become steeper as the number of c-axis oriented grains increases in the film samples A to B to C and the value of R_s (65 K) has been found to be the lowest for the highly c-axis oriented sample C. The variation of the resonant frequency of the dielectric resonator with temperature is shown in Figure 4. The computed values of $\lambda(0)$ have been found in the decreasing order in the samples A to B to C. The high-T_C superconductor is an inhomogeneous medium of superconducting grains coupled with Josephson weak links.

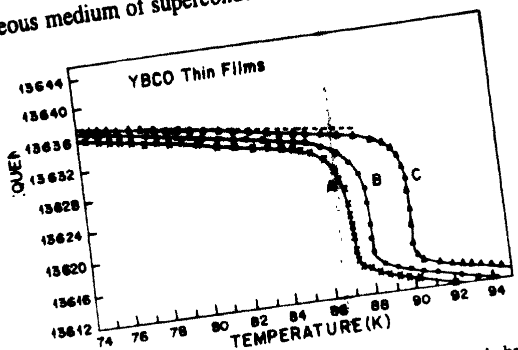

Figure 4. Variation of the resonant frequency (f_o) of the hybrid dielectric resonator with temperature.

The total surface resistance of the YBCO thin films in the superconducting state is given by eq. (4)

$$R_s(\text{Total}) = R_s(\text{Intragrain}) + R_s(\text{Intergrain}) + R_s(\text{others}). \tag{4}$$

As the temperature of the YBCO thin film sample is lowered below T_C(onset), the contribution due to R_s(Intragrain) and R_s(Intergrain) decreases and consequently R_s(Total) decreases. R_s(Intergrain) is dependent upon the strength of the Josephson coupling. The increase of Josephson coupling strength through increase of orientation of the grains has resulted in the lower value of R_s. In the randomly oriented samples, the measured value of the penetration depth $\lambda(T)$ is the function of the penetration depth λ_g in the superconducting grains and λ_j in the weak links. The value of λ_j is also dependent upon the strength of the Josephson coupling. As the degree of the orientation of the c-axis grains improves, the value of λ_j decreases. The value of $\lambda(0)$ has been found in the samples A, B and C equal to 1950, 1830 and 1650 Å respectively.

4. Conclusions

The study of R_s (10 and 13.6 GHz) and $\lambda(0)$ (13.6 GHz) conducted on oriented thin film samples suggests that with the grain alignment, the weak links are eliminated to a significant level and Josephson coupling gets tightened and the reduced values of these parameters are observed. The minimum achieved value of R_s (10 GHz, 65 K) for fully c-axis oriented thin film sample C is 600 μΩ, which could be reduced further reaching residual $R_s(0)$ value at 0 K. The value of residual penetration depth $\lambda(0) = 1650$ Å achieved for sample C is however, close to the London's microscopic value of 1400 Å.

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